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Projecting temperature-related years of life lost under different climate change scenarios in one temperate megacity, China☆

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ABSTRACT

Temperature has been associated with population health, but few studies have projected the future temperature-related years of life lost attributable to climate change. To project future temperature-related disease burden in Tianjin, we selected years of life lost (YLL) as the dependent variable to explore YLL attributable to climate change. A generalized linear model (GLM) and distributed lag non-linear model were combined to assess the non-linear and delayed effects of temperature on the YLL of non-accidental mortality. Then, we calculated the YLL changes attributable to future climate scenarios in 2055 and 2090. The relationships of daily mean temperature with the YLL of non-accident mortality were basically U-shaped. Both the daily mean temperature increase on high-temperature days and its drop on low-temperature days caused an increase of YLL and non-accidental deaths. The temperature-related YLL will worsen if future climate change exceeds 2 °C. In addition, the adverse effects of extreme temperature on YLL occurred more quickly than that of the overall temperature. The impact of low temperature was greater than that of high temperature. Men were vulnerable to high temperature compared with women. This analysis highlights that the government should formulate environmental policies to reach the Paris Agreement goal.

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1. Introduction

The World Health Organization (WHO) predicts that from 2030 to 2050, climate change will cause more than 250 thousand deaths each year from malnutrition, malaria, diarrhea and high temperatures (Zhou et al., 2008). Areas with weak health infrastructure (mostly in developing countries) will be the least able to prepare for and react to climate change without assistance. The impacts of climate change on health are more severe in children, the elderly, the infirm and groups with diseases. The fifth report of the Intergovernmental Panel on Climate Change (IPCC) stated that over the last 100 years, the global temperature has risen 0.85 °C. China's average annual temperature has increased significantly in the last 100 years, up to 0.5–0.8 °C, slightly higher than overall global warming during the same period. It is estimated that the climate will continue to warm in the future (Zeng et al., 2008).

Meteorological factors such as air temperature, humidity and pressure may affect the human nervous system, endocrine system, circulatory system, respiratory system, digestive system and other functions. As an important meteorological factor, temperature is closely related to the meteorological environment, human activity and human health. Heat waves have a negative impact on the daily deaths of coastal city residents, and the relationship between the city's daily all-cause deaths and daily mean temperature is "U" shaped (Gao et al., 2015). In addition, heat is an important cause of cardiovascular events (Cheng and Su, 2010; Halonen et al., 2011). However, hypothermia has adverse effects on population death, and its impact is greater on patients with coronary heart disease and cerebral embolism (Chen et al., 2016; Sartini et al., 2016). Additional literature has shown that a rise in daily mean temperature may lead to body dehydration and fatigue, and it is documented to be a risk factor for increased respiratory disease deaths. When greater than 25 °C, further temperature increases have a more obvious impact (Marchetti et al., 2016; YZ et al., 2012).

In previous studies on the relationships between daily mean temperature and health outcomes, more attention was paid to excess deaths or mortality risk, which usually weighted deaths for

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different age groups equally (Baccini et al., 2008; Le Tertre et al., 2006; McMichael et al., 2008; Medina-Ramon and Schwartz, 2007). It would be likely to miss differences in the life lost from different age groups (Yang et al., 2015), resulting in incomplete analysis of information. YLL can measure the death burden accurately and is mostly used to analyze the main cause of population life loss (Steenland and Armstrong, 2006). In recent years, some investigations explored the relationship between temperature and YLL (Egondi et al., 2015; J et al., 2016; Yang et al., 2015; Z et al., 2015). However, few have examined temperature-attributable YLL. This is the first study focusing on YLL attributable to high and low ambient temperature in Asia, even though three relevant studies were carried out in Australia and Europe (Baccini et al., 2013; Huang et al., 2012a, 2012b). Based on non-accidental death and YLL data in Tianjin from January 2006 to December 2011, we aimed to quantify total YLL attributable to heat and cold, and contributions from moderate and extreme temperatures, and to predict YLL under different climate scenarios in 2055 and 2090.

2. Materials and methods

2.1. Study area

Tianjin city is a metropolis in north China and covers an area of 11.917 thousand square kilometers. In 2015, its population reached 15.4695 million. It belongs to the warm temperate semi-humid continental monsoon climate with four distinct seasons. In summer, it is hot, and the rainfall is concentrated. In winter, it is cold, dry and with little snow.

2.2. Data collection

We collected time-series daily mortality data, weather variables and air pollutants from Tianjin. Mortality data included daily non-accidental mortality (International Classification of Disease (ICD)-10: A00~R99) in Tianjin from the China Centers for Disease Control and Prevention (CDC). Information about date of death, gender and age were provided. Meteorological data, including daily mean temperature and relative humidity, were provided by the China Meteorological Data Sharing Service System. The daily PM_{10} average value was from the Tianjin environmental monitoring center.

2.3. Statistical analysis

We first calculated YLL by matching each death by age and gender to the WHO life tables (http://apps.who.int/gho/data/view.main.60340?lang=en) (Table S1). Then, we applied a standard time-series regression to estimate the association between daily mean temperature and YLL after adjusting for the long-term trend, day of the week, and relative humidity. The regression included a natural spline of time with 7 degrees of freedom per year for the long-term trend and an indicator of the day of the week. Considering the possible lagging effects of temperature on YLL, we chose a distributed lag non-linear model (DLNM) (Gasparrini, 2011). DLNM is a two-dimensional function that captures both the non-linear and delayed effects of temperature. We employed the exposure-response curve with a quadratic B-spline with three knots (25th, 50^{th} and 75th percentiles) and a lag-response curve with a natural cubic B-spline with an intercept and three internal knots equally spaced on the log scale. We extended the lag period to 15 days to include the long delay of the effects of cold.

For each day of the series, we used the previous 15 days' cumulative effects corresponding to each day's YLL to calculate the attributable YLL. The total attributable YLL caused by non-optimum temperature is given by the sum of the contributions from all the days of the series. We calculated the components attributable to cold and heat by summing the subsets corresponding to days with temperature lower or higher than the minimum-mortality temperature. In addition, we extracted these components of extreme contributions by defining extreme cold and heat as temperature lower than the 2.5th percentile (extreme cold) and higher than the 97.5th percentile (extreme heat).

To estimate the uncertainty, we calculated empirical confidence intervals (eCIs) through Monte Carlo simulations, assuming a multivariate normal distribution of the reduced coefficients. The related 2.5th and 97.5th percentiles of these distributions are interpreted as the 95% eCIs.

According to the 5th IPCC, global warming is inevitable, and it will pose a risk to public health. We assumed that climate change will lead to an increase in mean air temperature, but the variability will not change. With the definition of representative concentration pathways (RCPs), four new scenarios were proposed in the IPCC Fifth Assessment Report (Pachauri et al., 2014). It assumed that the global average temperature would increase by 1.0 °C as under RCP2.6, 1.4 °C under RCP4.5, 1.3 °C under RCP6.0 and 2.0 °C under RCP8.5 for 2046–2065. In addition, the temperature would increase by 1.0 °C, 1.8 °C, 2.2 °C and 3.7 °C in the simulation for 2081–2100. Therefore, we simulated future daily temperatures by adding 1.0, 1.4, 1.3 and 2.0 °C to the observed daily temperature from 2006 to 2011 as the baseline for the simulation for 2046 to 2065, centred on 2055, and 1.0, 1.8, 2.2 and 3.7 °C for the projections for the years 2081–2100, centred on 2090.

3. Results

Table 1 shows the descriptive statistics of the variables. The mean temperature was in the range of −14.1 °C to 32.1 °C, with a mean of 13.1 °C, and its 25th and 75th percentiles were 2.1 °C and 23.8 °C, respectively. Humidity ranged from 15% to 97%, with a mean value of 58.1%, and its 25th and 75th percentiles were 44% and 72%, respectively. Mortality ranged from 13 to 340, with a mean of 148, and its 25th and 75th percentiles were 122 and 176, respectively. The dataset included 324,494 non-accidental deaths from January 2006 to December 2011, and the sum of YLL was 4,477,733.

Table 2 shows YLL in the baseline year 2008. We observed 53,230 (95%CI: 17,541–91,117) temperature-attributable YLL for men: 5980 (95%CI: 1927–10,044) YLL attributed to hot temperatures and 47,251 (95%CI: 10,289–86,125) YLL due to the cold. For women, we found 48,831 (95%CI: 19,707–81,992) temperature-attributable YLL: 3408 (95%CI: -83–6882) YLL attributed to hot temperatures and 45,422 (95%CI: 14,756–78,505) YLL due to the cold. In addition, the effect in men was greater than that in women. According to Tianjin Statistical Yearbook records, population in Tianjin reached 11.7600 million in 2008. There were totally 87 YLL for non-accidental deaths per 10,000 inhabitants; 8 YLL

Table 1
Summaries of the mortalities and meteorological and pollutant data in Tianjin, 2006–2011.

Data	Min	25th	50th	75th	Max	Mean	IQR
PM_{10}(μg/m3)	10	60	88	124	503	101.6	64
Mean temperature (°C)	−14.1	2.1	14.4	23.8	32.1	13.1	21.7
RH (%)	15	44	60	72	97	58.1	28
Mortality (count)	13	122	152	176	340	148	54
YLL (years)	172	1716	2095	2409	4368	2043	692

RH: relative humidity; PM_{10}: particulate matter with an aerodynamic diameter of less than 10 μm in size; YLL: years of life lost.

Table 2
YLL attributable to temperature in baseline year 2008 in Tianjin (1/10,000).

	Population[a] (million)	YLL			YLL Per 10,000 Inhabitants		
		Heat	Cold	Sum	Heat	Cold	Sum
Total	11.7600	9388	92,673	102,061	8	79	87
Men	6.0783	5980	47251	53230	10	78	88
Women	5.6817	3408	45422	48831	6	80	86

[a] Population data from Tianjin Statistical Yearbook (2008), http://www.stats-tj.gov.cn/2010/01/18/10582213026.html.

attributable to heat and 79 YLL attributable to cold per 10,000.

Fig. 1 shows the exposure-response curves between daily mean temperature and YLL. The curves were approximately U-shaped, with nearly identical optimum mortality temperature for men and women (24 °C). For days with a mean temperature of −5.9 °C, there were 480 years of life lost for women (95% CI: 270–691), and 444 years of life lost for men (95% CI: 199–689). For days with a mean temperature of 29.1 °C, there were 113 years of life lost for women (95% CI: 25–201), and 186 years of life lost for men (95% CI: 83–290). Similar results were observed for non-accidental deaths.

The delayed effects of extreme temperature on mortality risk and YLL are shown in Figs. S1 and S2. The 2.5th percentile of daily mean temperature (−5.9 °C) was chosen as representative of cold days (Fig. S1), and to represent hot days, we chose the 97.5th percentile (29.1 °C) (Fig. S2). The effect of heat was typically immediate. It tended to be obviously higher than the effect of cold at 0 day lag time; then, it declined rapidly, while the effect of cold peaked 5 days after exposure and then decreased slightly. At the lag time of 15 days, the effect of cold was slightly stronger than the effect of heat. This meant that the cold effect lasted longer than the heat effect. In addition, for both extreme cold and heat effects, the hysteresis between men and women was similar. However, at extreme cold temperatures, the YLL change in females was greater than that in males, and the delayed days of the effect in females was also longer. At extreme high temperatures, the situation was the

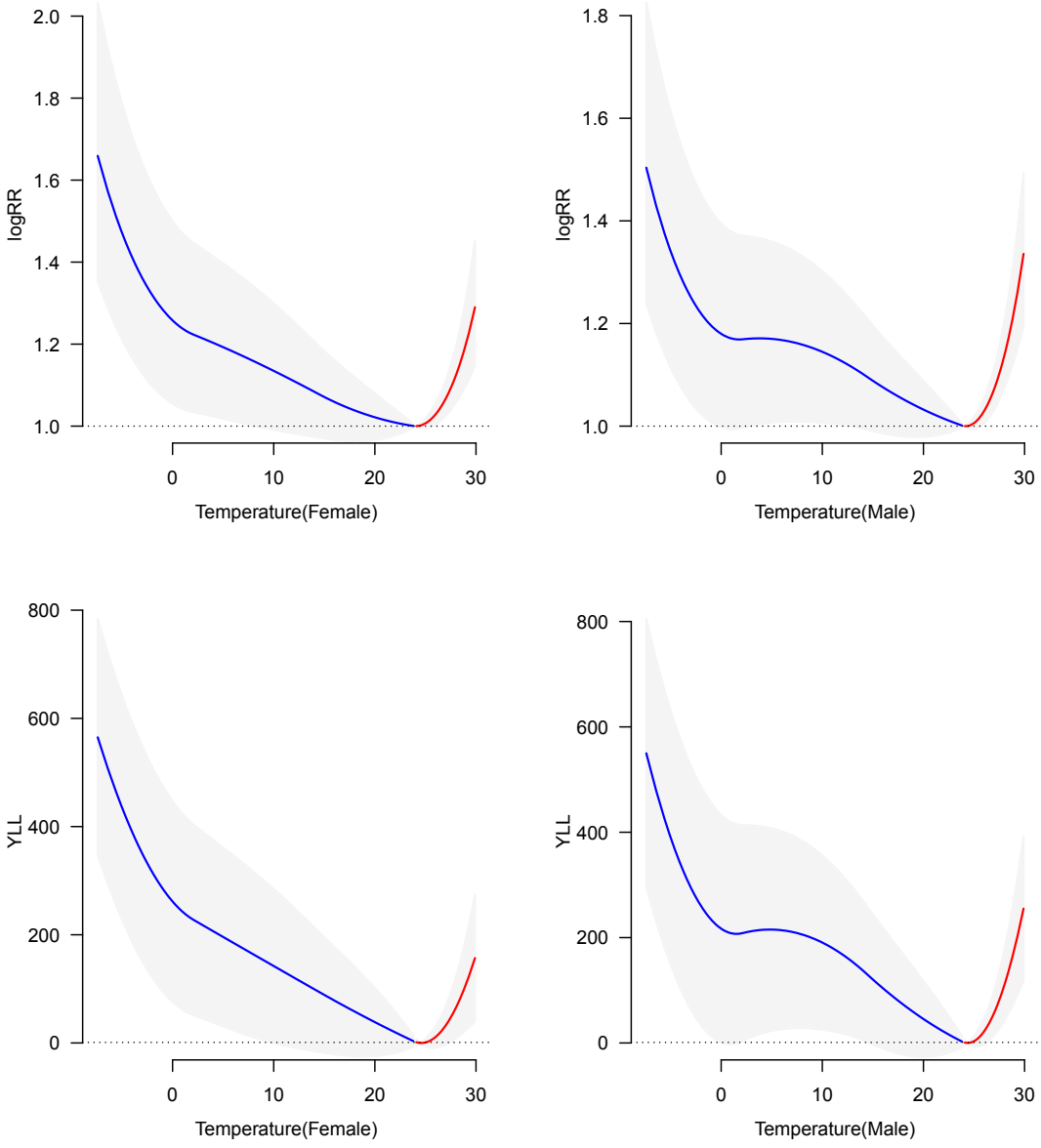

Fig. 1. Effects of temperature on mortality risk and years of life lost in Tianjin, China, 2006–2011. The solid line shows the mean; gray areas show the 95% confidence intervals.

opposite. YLL in men was obviously higher than that in women, which meant heat-related effects lasted longer in men.

Tables 3 and 4 show the measured temperature-attributable YLL in 2008, 2055 and 2090, with the center from 2006 to 2011 as a baseline, and from 2046 to 2065 and 2081 to 2100 for simulation, based on the RCPs proposed in the IPCC Fifth Assessment Report. We found that estimates of YLL are less than the baseline, with a temperature rise from 1.0 °C to 2.0 °C. For men, changes of heat-related effects were more obvious than that of cold effects, while for women, the situation was the opposite. Therefore, men are more susceptible to high temperatures, while women are more susceptible to low temperatures. When we assumed a 2.2 °C increase, the situation began to change. A total increase of 584 (95% CI:-1456–2623) temperature-attributable YLL was observed, including an increase of 2607 (95% CI: 1091–4122) YLL for men and a decrease of 2023 (95% CI: −3387–-659) YLL for women. This total increase indicated that the increased heat-attributable YLL was not counteracted by the decreased cold effect.

In addition, the study provided evidence for the effects of extreme temperatures on YLL. Tables 5 and 6 show the simulated YLL attributable to extreme high temperatures in 2055 and 2090, respectively. There were 16,279 (95% CI: 16,092–16,347) YLL at baseline, including 8347 (95% CI: 8250–8444) YLL for the men and 7872 (95% CI: 7790–7955) for the women. With a 1.0 °C increase in extreme temperature, a total increase of 289 (95% CI: 103–475) YLL was observed, indicating that the increased extreme heat-related YLL could not be counteracted by decreased extreme cold-related effect. With the extreme temperature continuously increasing, YLL continued to rise and grow significantly. From the two tables we found that compared with YLL increase caused by moderate temperature, extreme temperature could bring about a more intense effect, indicating that it is essential to control the rise of temperature increase. Gender differences also partly confirm that extreme heat has a higher impact on men than women.

Fig. 2 depicts the changes in YLL compared with the baseline year. The abscissa represents the predicted increase in temperature, and the ordinate represents the change in YLL. The year 2008 was chosen as the baseline, and the YLL changes caused by its moderate temperature and extreme temperature is indicated by the dotted line with the ordinate of 0. For the effects of moderate temperature, we found that the change in YLL had a nearly J-shaped and showed adverse effects above 2.2 °C. For the effects of extreme temperature, the effects showed adverse effects with temperature increase.

4. Discussion

This study suggested that the daily mean temperature in Tianjin from January 2006 to December 2011 had a non-linear relationship with YLL and mortality risk. Its exposure-response relation curve was basically a U-shaped, with an optimum temperature of 24 °C, and both the increase of the high temperature and decrease of the low temperature would increase non-accidental deaths and YLL. Related literature at home and abroad has demonstrated that the relation between daily mean temperature and death was basically U-, J-, or W-shaped (Armstrong, 2006; Braga et al., 2002; Gasparrini and Armstrong, 2010), which was consistent with our research results. After considering the lag effect, it was found that the impact of high temperature was usually shorter, and the strongest effect appeared on the exposed day. Compared with the high-temperature effects, the impact of low temperature often lagged and lasted longer, which was consistent with the related literature conclusions (Anderson and Bell, 2009; Orru and Astrom, 2016).

Huang et al. 2012a,b carried out their study for Brisbane (27°28′S), the third largest city in Australia (Huang et al., 2012b), with the population of 882,259 in the baseline year 2000 (http://

Table 3
Baseline and projected YLL due to moderate temperature in Tianjin, China in 2055.

	Baseline	Climate change							
		1.0 °C increase		1.3 °C increase		1.4 °C increase		2.0 °C increase	
		Projection	Change	Projection	Change	Projection	Change	Projection	Change
Women									
heat	3408	5942	2534	6902	3494	7244	3836	9552	6143
	(−83,6882)	(519,11287)	(2333,2734)	(668,12965)	(3275,3713)	(722,13508)	(3610,4062)	(1388,17335)	(5872,6414)
cold	45422	41006	−4416	39785	−5638	39389	−6034	37110	−8313
	(14756,78505)	(12173,72685)	(−5812,−3021)	(11449,71068)	(−7022,−4253)	(11216,70545)	(−7415,−4653)	(9845,66818)	(−9673,−6953)
glob	48831	46948	−1883	46687	−2144	46633	−2198	46661	−2170
	(19707,81992)	(18985,77881)	(−3264,−502)	(18923,77246)	(−3518,−769)	(18905,77141)	(−3570,−825)	(19296,76987)	(−3535,−804)
Men									
heat	5980	10136	4157	11696	5716	12250	6271	15969	9990
	(1927,10044)	(3857,16510)	(3890,4423)	(4495,18733)	(5425,6008)	(4703,19562)	(5970,6572)	(6423,25066)	(9625,10354)
cold	47251	42887	−4363	41704	−5546	41323	−5927	39153	−8098
	(10289,86125)	(7891,79578)	(−5884,−2843)	(6920,77704)	(−7055,−4038)	(6658,77125)	(−7432,−4423)	(5734,73762)	(−9579,−6616)
glob	53230	53023	−207	53400	170	53574	344	55122	1892
	(17541,91117)	(20057,89183)	(−1726,1313)	(20546,89399)	(−1345,1685)	(20738,89395)	(−1170,1858)	(22696,89888)	(378,3406)
Total									
heat	9388	16078	6690	18598	9210	19495	10107	25521	16133
	(9207,9569)	(15798,16358)	(6357,7024)	(18281,18915)	(8846,9575)	(19165,19825)	(9731,10483)	(25104,25937)	(15678,16587)
cold	92673	83893	−8780	81489	−11184	80712	−11961	76263	−16410
	(91173,94174)	(82476,85310)	(−10844,−6716)	(80096,82882)	(−13231,−9136)	(79327,82097)	(−14003,−9919)	(74923,77602)	(−18422,−14399)
glob	102061	99971	−2089	100088	−1973	100207	−1854	101783	−278
	(100580,103542)	(98550,101393)	(−4143,−36)	(98677,101498)	(−4019,72)	(98799,101615)	(−3898,190)	(100383,103183)	(−2316,1761)

Baseline for the years 2006–2011 centred on 2008; Projection for the years 2046–2065 centred on 2055. Heat and cold refer to daily mean temperature above and below the optimum mortality temperature(24 °C). 95% confidence intervals are shown in brackets.

Table 4
Baseline and projected YLL due to moderate temperature in Tianjin, China in 2090.

	Baseline	Climate change							
		1.0 °C increase		1.8 °C increase		2.2 °C increase		3.7 °C increase	
		Projection	Change	Projection	Change	Projection	Change	Projection	Change
Women									
heat	3408	5942	2534	8732	5324	10420	7012	18702	15293
	(−83,6882)	(519,11287)	(2333,2734)	(1116,15909)	(5069,5579)	(1673,18854)	(6723,7301)	(3697,32826)	(14834,15752)
cold	45422	41006	−4416	37852	−7571	36387	−9035	31498	−13924
	(14756,78505)	(12173,72685)	(−5812,−3021)	(10290,68078)	(−8938,−6204)	(9356,65586)	(−10388,−7682)	(6046,58009)	(−15230,−12619)
glob	48831	46948	−1883	46584	−2247	46808	−2023	50200	1369
	(19707,81992)	(18985,77881)	(−3264,−502)	(19242,77035)	(−3614,−880)	(19451,77206)	(−3387,−659)	(21572,82069)	(−21,2759)
Men									
heat	5980	10136	4157	14653	8673	17363	11383	30508	24529
	(1927,10044)	(3857,16510)	(3890,4423)	(5709,23079)	(8331,9015)	(7131,27241)	(10994,11772)	(13206,46733)	(23905,25152)
cold	47251	42887	−4363	39855	−7396	38474	−8776	34021	−13230
	(10289,86125)	(7891,79578)	(−5884,−2843)	(6025,74864)	(−8885,−5906)	(5462,72680)	(−10251,−7302)	(3301,65086)	(−14653,−11807)
glob	53230	53023	−207	54508	1278	55837	2607	64529	11299
	(17541,91117)	(20057,89183)	(−1726,1313)	(21704,89620)	(−235,2790)	(22939,90944)	(1091,4122)	(31277,101558)	(9718,12879)
Total									
heat	9388	16078	6690	23385	13997	27783	18395	49210	39822
	(9207,9569)	(15798,16358)	(6357,7024)	(22999,23772)	(13571,14424)	(27334,28232)	(17911,18879)	(48457,49963)	(39048,40596)
cold	92673	83893	−8780	77706	−14967	74862	−17811	65519	−27154
	(91173,94174)	(82476,85310)	(−10844,−6716)	(76352,79061)	(−16988,−12945)	(73537,76186)	(−19813,−15810)	(64303,66734)	(−29085,−25224)
glob	102061	99971	−2089	101092	−969	102645	584	114729	12668
	(100580,103542)	(98550,101393)	(−4143,−36)	(99691,102492)	(−3008,1070)	(101243,104046)	(−1456,2623)	(113233,116224)	(10563,14773)

Baseline for the years 2006–2011 centred on 2008; Projection for the years 2081–2100 centred on 2090. Heat and cold refer to daily mean temperature above and below the optimum mortality temperature(24 °C). 95% confidence intervals are shown in brackets.

www.abs.gov.au/websitedbs/D3310114.nsf/home/Home). In 2000, they observed 1519 heat-related YLL and 5053 cold-related YLL, indicating 17 YLL attributable to heat and 57 YLL attributable to cold per 10,000 inhabitants in Brisbane. While in the baseline year, we observed 8 heat-related YLL and 75 cold-related YLL per 10,000 habitants in Tianjin (39°13′N). It could be implied that in high latitudes, death caused by high temperatures is less than that in low latitudes. Baccini et al., 2013 examined heat-related YLL in 14 European cities during the 1990s using maximum apparent temperature as exposure index and found positive results (Baccini et al., 2013). The rule above is still feasible in most cities. The largest annual YLL per 10,000 inhabitants in the 15–64 class was observed in Valencia (39°28′N), Rome (41°54′N) and Barcelona (41°18′N). The lowest annual YLL was observed in Dublin (53°26′N), London (51°30′N) and Zurich (47°22′N). However, further studies are needed to verify roles of latitudes in the relationship between climate change and health.

The impacts of low temperature on women was higher than that on men, with the opposite trend for high temperature, which is consistent with a previous study (Yu et al., 2010). Donaldson GC found that men wore 0.14 clo (1 clo = 0.115 m^2 K W-1) more than women ($P < 0.001$), which may be one of the reasons for women's poor tolerance to hypothermia (Donaldson et al., 2001). Additionally, physiological characteristics and differences in socioeconomic status and ability to withstand stress between genders may also lead to the increased sensitivity of women at low temperatures (Seeman et al., 2002). For the heat effect, high-temperature operation in summer is mostly done by men, which may lead to the greater impact of high temperature on men.

We compared the health effects caused by temperature below and above the optimal value, respectively. Cold was associated with the vast majority of the burden, whereas thermal effects provided only a small part. This difference is mainly due to the high percentile of the minimum-mortality temperature, which means the majority of daily mean temperatures are below the optimal value and people live in a relatively cold environment. In addition, multiple studies have investigated the impact of extreme temperature on mortality and YLL (De Sario et al., 2013; Green et al., 2012; Masato et al., 2015; Xie et al., 2014), similar to our study. This great impact indicates a need to establish and improve the early warning system, develop emergency plans, inform people to improve awareness of extreme weather risk and enhance adaptive capacity through physical exercise (Knowlton et al., 2009). Extreme weather, such as high-temperature warnings, should be considered with great importance and be responded to quickly by hospital emergency admissions and ambulance call-outs (Abrahamson and Raine, 2009; Ibrahim et al., 2012). When addressing extreme low temperature, we should prepare for long-term response to the low-temperature effects. Compared to high temperature, the response measures need to continue for a longer period of time (Hess et al., 2009; Thornes et al., 2014).

As a new scenario characterized by stable concentrations, RCPs were applied to various estimates of the climate model, impact, adaptation, and mitigation. They provide consistent predictions of emissions and concentrations of radioactive gases and particulates over time (Dai et al., 2016; Moss et al., 2010; Paulot et al., 2013). For example: RCP2.6 is characterized by a peak in radiative forcing at ~3 W/m^2 before 2100 and a decrease to 2.6 W/m^2 by 2100, with very low greenhouse gas emissions (van Vuuren et al., 2011). Global warming is usually associated with serious health effects. It has been suggested that a 2.0 °C increase in temperature should be regarded as a safe limit (Drijfhout et al., 2015), similar to the conclusions of our study. In our simulation results, with a temperature increase of 2.0 °C, the reduced cold-attributable YLL still offset the elevated heat-attributable YLL. However, with an increase of 2.2 °C,

Table 5
Baseline and projected YLL due to extreme temperature in Tianjin, China in 2055.

	Baseline	Climate change							
		1.0 °C increase		1.4 °C increase		1.3 °C increase		2.0 °C increase	
		Projection	Change	Projection	Change	Projection	Change	Projection	Change
Women									
extreme	1419	2056	638	2271	852	2344	926	2812	1393
heat	(233,2515)	(443,3616)	(578,697)	(500,3992)	(789,915)	(527,4122)	(861,990)	(699,4943)	(1320,1466)
extreme	6454	5840	−614	5668	−786	5612	−842	5288	−1166
cold	(4262,8877)	(3685,8189)	(−719,−509)	(3519,8010)	(−890,−681)	(3472,7970)	(−946,−737)	(3191,7608)	(−1270,−1062)
total	7872	7897	24	7939	66	7956	84	8099	227
	(7790,7955)	(7809,7984)	(−96,145)	(7849,8029)	(−56,189)	(7866,8047)	(−39,207)	(8003,8196)	(100,354)
Men									
extreme	2340	3334	995	3667	1328	3782	1442	4505	2166
heat	(972,3613)	(1489,5134)	(925,1064)	(1645,5641)	(1254,1401)	(1698,5822)	(1367,1517)	(2033,6948)	(2080,2251)
extreme	6007	5277	−730	5077	−930	5012	−995	4643	−1364
cold	(3369,8802)	(2786,8087)	(−853,−607)	(2614,7908)	(−1053,−808)	(2551,7845)	(−1118,−873)	(2204,7402)	(−1486,−1242)
total	8347	8611	265	8744	397	8793	447	9148	802
	(8250,8444)	(8509,8714)	(123,406)	(8639,8849)	(254,540)	(8687,8899)	(303,590)	(9036,9261)	(653,950)
Total									
extreme	3758	5391	1633	5938	2180	6126	2368	7317	3559
heat	(3704,3812)	(5317,5465)	(1541,1724)	(5857,6019)	(2083,2277)	(6043,6209)	(2269,2467)	(7218,7415)	(3446,3671)
extreme	12461	11117	−1344	10745	−1716	10624	−1837	9931	−2530
cold	(12345,12577)	(11004,11230)	(−1505,−1182)	(10632,10857)	(−1877,−1555)	(10512,10736)	(−1998,−1676)	(9820,10041)	(−2690,−2370)
total	16219	16508	289	16682	463	16750	531	17247	1028
	(16092,16347)	(16373,16643)	(103,475)	(16544,16821)	(275,652)	(16610,16889)	(342,720)	(17099,17396)	(833,1224)

Baseline for the years 2006–2011 centred on 2008; Projection for the years 2046–2065 centred on 2055. Extreme heat refers to daily mean temperature above 29.1 °C and extreme cold refers to temperature below −5.9 °C. 95% confidence intervals are shown in brackets.

Table 6
Baseline and projected YLL due to extreme temperature in Tianjin, China in 2090.

	Baseline	Climate change							
		1.0 °C increase		1.8 °C increase		2.2 °C increase		3.7 °C increase	
		Projection	Change	Projection	Change	Projection	Change	Projection	Change
Women									
extreme	1419	2056	638	2651	1233	2977	1558	4365	2946
heat	(233,2515)	(443,3616)	(578,697)	(643,4664)	(1163,1303)	(752,5214)	(1482,1635)	(1243,7603)	(2843,3050)
extreme	6454	5840	−614	5393	−1061	5184	−1269	4488	−1966
cold	(4262,8877)	(3685,8189)	(−719,−509)	(3284,7738)	(−1165,−956)	(3068,7499)	(−1373,−1166)	(2458,6813)	(−2068,−1864)
total	7872	7897	24	8044	172	8161	289	8853	981
	(7790,7955)	(7809,7984)	(−96,145)	(7950,8139)	(47,298)	(8063,8260)	(160,418)	(8733,8973)	(835,1126)
Men									
extreme	2340	3334	995	4257	1917	4760	2421	6899	4560
heat	(972,3613)	(1489,5134)	(925,1064)	(1918,6571)	(1836,1999)	(2159,7316)	(2332,2510)	(3265,10567)	(4439,4681)
extreme	6007	5277	−730	4762	−1245	4528	−1479	3786	−2221
cold	(3369,8802)	(2786,8087)	(−853,−607)	(2310,7546)	(−1367,−1123)	(2105,7278)	(−1601,−1358)	(1413,6580)	(−2340,−2101)
total	8347	8611	265	9019	672	9288	942	10686	2339
	(8250,8444)	(8509,8714)	(123,406)	(8909,9129)	(526,819)	(9173,9403)	(791,1092)	(10546,10826)	(2169,2509)
Total									
extreme	3758	5391	1633	6908	3150	7737	3979	11264	7506
heat	(3704,3812)	(5317,5465)	(1541,1724)	(6815,7001)	(3042,3258)	(7633,7841)	(3862,4096)	(11114,11414)	(7347,7666)
extreme	12461	11117	−1344	10155	−2306	9712	−2749	8274	−4186
cold	(12345,12577)	(11004,11230)	(−1505,−1182)	(10044,10266)	(−2466,−2145)	(9602,9822)	(−2908,−2589)	(8168,8381)	(−4344,−4029)
total	16219	16508	289	17064	844	17449	1230	19539	3320
	(16092,16347)	(16373,16643)	(103,475)	(16918,17209)	(651,1038)	(17298,17601)	(1032,1428)	(19355,19723)	(3096,3544)

Baseline for the years 2006–2011 centred on 2008; Projection for the years 2081–2100 centred on 2090. Extreme heat refers to daily mean temperature above 29.1 °C and extreme cold refers to temperature below −5.9 °C. 95% confidence intervals are shown in brackets.

the situation began to deteriorate. The substantial increase in heat-attributable YLL could not be counteracted by the slightly decreased cold effect. This result was corroborated by the Paris Agreement on November 4, 2016, which aims to control the temperature rise within 2.0 °C.

Fig. 2 shows that compared with the YLL increase caused by moderate temperature, extreme temperature could cause a more intense effect. Under extreme temperatures, the increased heat-related effect at lower temperatures could not be offset by the reduced cold-related effect, and YLL would rise quickly to reach the baseline and continue to grow significantly. It suggested that we should improve and attach importance to awareness and prevention of extreme temperatures and strengthen the development and promotion of monitoring and early warning systems.

Most previous studies reported the relative risk of mortality and did not consider differences in mortality at different ages. Our main advantage is that we used YLL as a measure of the contribution of temperature to death. Compared to the relative risk of mortality, YLL focuses mainly on young people's premature death, which is essential for risk assessment and decision making. However, there

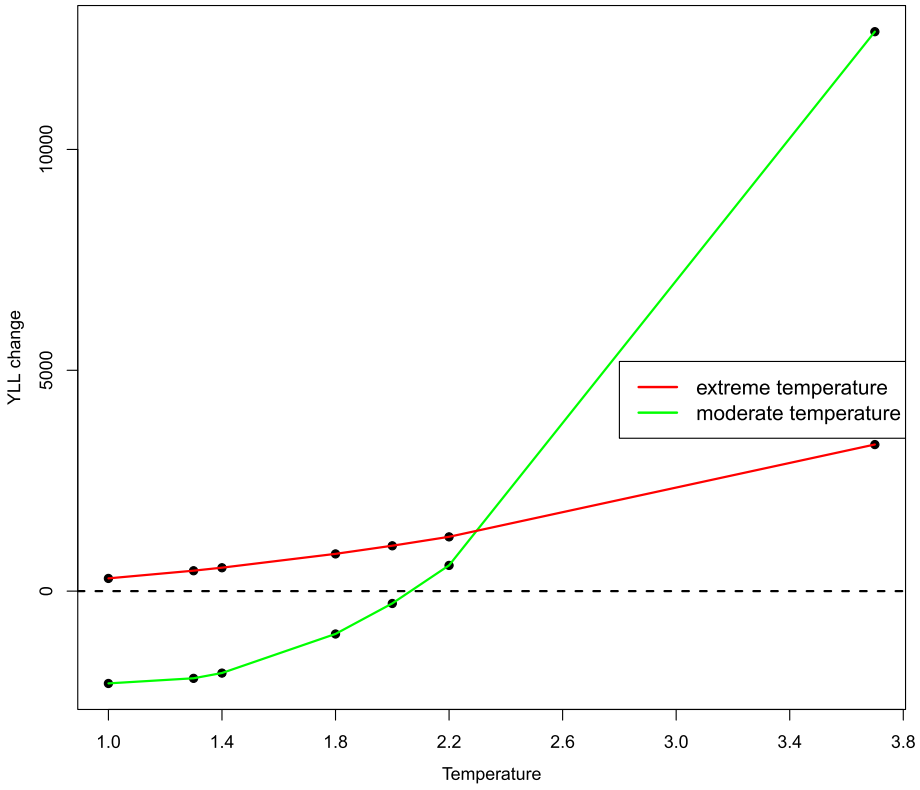

Fig. 2. Projections of temperature-related years of life lost compared to the baseline.

is no research about estimates of temperature-attributable YLL in China. We adopted feasible statistical models to estimate the association between daily mean temperature and YLL of non-accidental death. This study took YLL in Tianjin as the dependent variable, controlled for other air pollutants and meteorological factors, and established a generalized additive model of time series with daily mean temperature to reduce the occurrence of mixed and ecological fallacies. In addition, combined with the distributed lag model, the study fully considered the lag effect of temperature to study the effect of daily mean temperature on death burden.

This study has some limitations. First, our temperature data were collected from environmental monitoring stations, which may not be a precise representative of individual exposure. Second, there were only two controlled atmospheric pollutants and meteorological factors, PM_{10} and daily humidity. Some studies have shown that $PM_{2.5}$ and SO_2 are associated with population death (Chen et al., 2017; Uccelli et al., 2016). However, there are also studies suggesting that the impact of temperature on death is far greater than that of air pollution, which will not produce obvious confounding bias (Spickett et al., 2011). There may be additional confounding factors, such as economic and medical conditions, social status change or influenza, affect non-accidental death outcomes, and these factors cannot be controlled for due to the limitations of the data. Therefore, further studies need to consider these confounding factors as comprehensively as possible to obtain a more accurate exposure-response relationship. Third, we applied the baseline temperature-YLL relationship to the simulation in 2008, which may lead to an underestimated simulation due to the aging society and population change. In future studies, we will adopt a better crowd temperature exposure method and include confounding factors, such as socioeconomic status and atmospheric pollutants, to obtain a more accurate estimate of the relationship between temperature and YLL. We will also consider the differences among different populations and analyze the contributions of temperature and different age groups to YLL. Meanwhile, similar studies in cities at different latitudes should be done to determine whether in the relationship of YLL and temperature, the contribution of low temperature to YLL is greater than that of high temperature at high latitude regions to offset the YLL risk prediction of temperature increase.

5. Conclusions

In summary, our study provides evidence for the disease burden of ambient daily mean temperatures in China. We found that the effects of cold temperatures on women were greater than those on men, with the opposite trend for hot temperatures. The association between extreme temperature and YLL showed a sharp change compared to that of moderate temperature. Taking the scenarios proposed by IPCC into consideration, we found an increase in YLL. Professional preventive and controlling measures are required to protect public health.

Competing interests

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.envpol.2017.10.008.

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